JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1978, 29, 161-166 NUMBER 2 (MARCH)

EFFECT OF VARIABLE-INTERVAL PUNISHMENT ON THE BEHAVIOR OF HUMANS IN VARIABLE-INTERVAL SCHEDULES OF MONETARY REINFORCEMENT[1]

C. M. BRADSHAW, E. SZABADI, AND P. BEVAN

UNIVERSITY OF MANCHESTER

One male and three female human subjects pressed a button for monetary reinforcement under a range of variable-interval schedules specifying different frequencies of reinforcement. On alternate days, responding was also punished (by subtraction of money) according to a variable-interval 170-second schedule. In the absence of punishment, the rate of responding was an increasing negatively accelerated function of reinforcement frequency, as predicted by Herrnstein's equation. The effect of the punishment schedule was to suppress responding under lower frequencies of reinforcement; responding under higher reinforcement frequencies was much less affected. This was reflected in an increase in the value of K_H (the constant expressing the reinforcement frequency corresponding to the half-maximal response rate), whereas there was no significant change in the value of R_{max} (the constant expressing the maximum response rate). Previous results had shown that variable-ratio punishment resulted in a change in the values of both constants (Bradshaw, Szabadi, and Bevan, 1977). The results of the present study were consistent with the concept that the suppressive effects of punishment on responding depend on the nature of the punishment schedule.

Key words: Herrnstein's equation, response rate, reinforcement frequency, variable interval, variable-interval punishment, button pressing, humans

---

The relationship between response rate and reinforcement frequency in variable-interval (VI) schedules can be described by the following equation (Herrnstein, 1970):

$$R = R_{max} \cdot r/(K_H + r) \qquad (1),$$

where R is the response rate, and r the reinforcement frequency. R_{max} and K_H are constants that express the maximum response rate and the reinforcement frequency corresponding to the half-maximal response rate, respectively (Bradshaw, 1977; Bradshaw, Szabadi, and Bevan, 1976; Herrnstein, 1974). This equation defines a rectangular hyperbola. Variables that suppress responding maintained by VI schedules may be classified according to their effects on the values of the two constants in Equation (1) (*i.e.*, K_H and R_{max}). Three patterns of response suppression are possible: (i) a reduction of the value of R_{max}, (ii) an increase in the value of K_H, and (iii) a combination of both these effects (Bradshaw, 1977; Bradshaw *et al.*, 1977).

In previous experiments (Bradshaw *et al.*, 1976, 1977) we have found that the behavior of human subjects under VI schedules conforms to Equation (1). We also observed that response suppression resulting from the concurrent availability of an alternative source of reinforcement belongs to the second of the three categories listed above (Bradshaw *et al.*, 1976), whereas response suppression brought about by punishment delivered under a variable-ratio (VR) schedule belongs to the third category (Bradshaw *et al.*, 1977).

Azrin and Holz (1966) suggested that the effects of punishment depend jointly on the schedule of reinforcement that maintains responding, and on the particular type of punishment schedule employed. We have, therefore, examined whether the pattern of response suppression observed in our previous experiment was peculiar to VR punishment, or whether the same pattern would occur when punishment was delivered according to an interval schedule.

---

[1]This work was supported by grants from the North Western Regional Health Authority of Great Britain and the Faculty of Medicine, University of Manchester (Needham Fund). We are grateful to Mrs. E. A. Markham and Mrs. M. Gill for technical assistance. Reprints may be obtained from C. M. Bradshaw, Department of Psychiatry, University of Manchester, Stopford Building, Oxford Road, Manchester M13 9PT, U.K.

METHOD

Subjects

Four volunteer subjects served: KD (male, 23 yr), CW (female, 30 yr), HB (female, 38 yr) and JC (female, 35 yr). All were experimentally naive at the start of training, and had no previous training in psychology.

Apparatus

Experimental sessions took place in a small room. The same apparatus was used as in our previous experiment (Bradshaw *et al.*, 1977). The subject sat at a desk facing a sloping panel (40 cm wide and 30 cm high) on which were mounted a row of five amber lights (labelled 1 to 5 from left to right) 2 cm from the top of the panel, a digital counter situated in the center of the panel, and a green and a red light mounted side by side 1 cm below the counter. The green and red lights were labelled "WIN" and "LOSE" respectively. In front of the panel was a button that could be depressed by a force of approximately 6 N. Auditory response feedback was provided by a relay situated behind the panel. Pinned to the wall facing the subject was a notice on which was written either "GOOD DAY" or "BAD DAY" referring to the presence or absence of the punishment schedule (see Procedure).

Conventional electromechanical programming and recording equipment was situated in another room, judged by the experimenters to be out of earshot from the experimental room. Additional masking noise was provided by a radio.

Procedure

The instructions given to the subjects were identical to those described by Bradshaw *et al.* (1977).

On the first day of training the subjects were instructed as follows:

> "This is a situation in which you can earn money. You earn money simply by pressing this button. Sometimes when you press the button the green light will flash on: this means you will have earned one penny. The total amount of money you have earned is shown on this counter. You will start each day with 25p registered on the counter; every time the green light flashes it adds one point to the total score. (Please ignore the red light; it will not apply to you for the first two days). When operating the button make sure you press hard enough. You can tell whether you have pressed hard enough by listening for a slight click coming from inside the box. Now look at these orange lights. When one of the orange lights is on, it means that you are able to earn money. At the beginning of the session one of the lights will come on and will stay on for 10 minutes and throughout this time you may earn money. At the end of 10 minutes the light will go off for 5 minutes and during this time you should rest. After the rest period, another light will come on, again for 10 minutes, and you may earn some more money. Then there will be another rest period, and so on until each of the five orange lights has been presented. At the end of the session we will take the reading from the counter and note down how much you have earned. You will be paid in a lump sum at the end of the experiment."

The five amber lights were each associated with a different VI schedule. Constant-probability schedules were used, as described by Catania and Reynolds (1968). The reinforcement frequencies specified by the schedules were as follows: 1: 445 reinforcements per hour (VI 8-sec); 2: 211 reinforcements per hour (VI 17-sec); 3: 70 reinforcements per hour (VI 51-sec); 4: 21 reinforcements per hour (VI 171-sec); 5: 5 reinforcements per hour (VI 720-sec). Reinforcement was signalled by a 100-msec illumination of the green light and the addition of one point to the score displayed on the counter.

On the third day, the subjects received the following additional instructions:

> "The last two days were 'Good Days'. Today, and every alternate day from now on, will be a 'Bad Day'. On 'Bad Days' you will not only stand a chance of winning money, but also of losing money. Sometimes when you press the button the red light will flash and one penny will be subtracted from your total score displayed on the counter. As usual, 'wins' will be signalled by the green light."

On "Bad Days", punishment, consisting of a 100-msec illumination of the red light and the subtraction of one point from the score displayed on the counter, was delivered according to a VI 170-sec schedule, irrespective of which VI reinforcement schedule was in operation. If a reinforcement and a punishment were both scheduled for the same response, both the green and red lights were illuminated, but the score displayed on the counter did not change.

The five VI schedules were presented in a random sequence, with the constraint that each schedule occurred in a different ordinal position on successive days. Alternating 10-min schedule presentations with 5-min timeout periods was used in an effort to minimize behavioral interaction between the individual schedules (see Bradshaw *et al.,* 1976). Experimental sessions took place at the same time each day on 30 successive working days, except in the case of KD, who withdrew from the experiment after 25 days. Visual inspection of the raw data indicated that the behavior of all four subjects had reached stability after 10 to 15 sessions.

RESULTS

Performance in the Absence of Punishment

Figure 1 (closed circles) shows, for each subject, the mean response rates (R ± s.e.m.) recorded under each schedule during the last three "Good Days" (no punishment), plotted against delivered reinforcement frequency (r). (A sample cumulative record obtained from one subject, KD, is shown in Figure 2.) For all four subjects, response rate was an increasing, negatively accelerated function of reinforcement frequency, approaching an asymptote at high values of reinforcement frequency. Rectangular hyperbolae were fitted to the data using nonlinear regression analysis (Wilkinson, 1961). This method gives estimates (± s.e.est.) of the theoretical maximum response rate (R_{max}) and the reinforcement frequency corresponding to the half-maximal re-

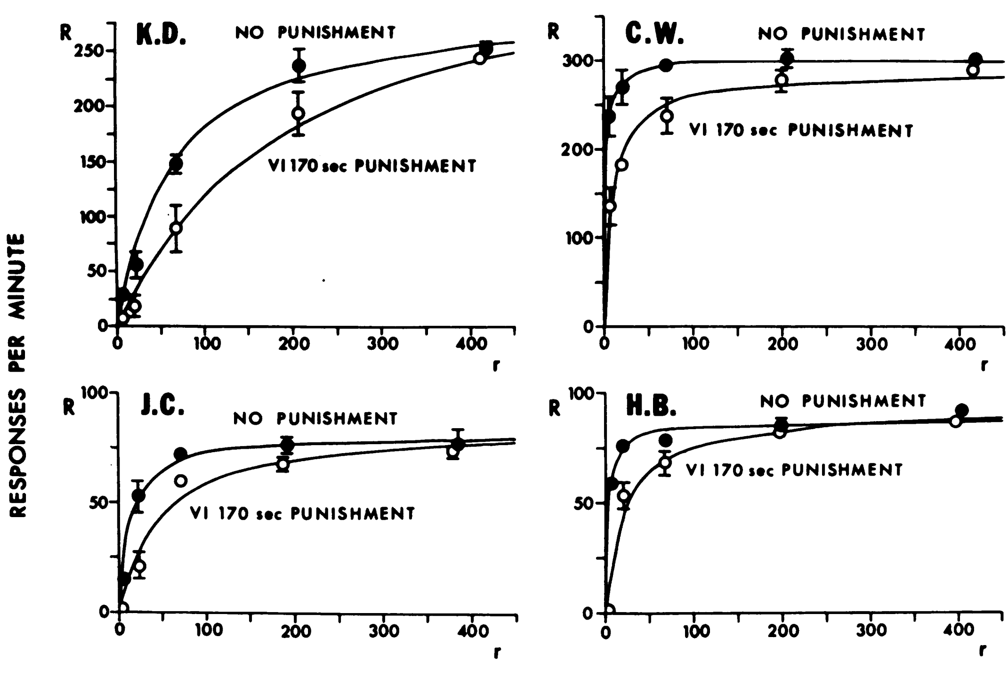

Fig. 1. Relationship between response rate (R) and reinforcement frequency (r) in variable-internal scheduels of monetary reinforcement for four subjects. Points are mean response rates (± s.e.m.) for last three sessions in the absence of punishment (closed circles) and in the presence of VI 170-sec punishment (open circles). Curves are best-fit rectangular hyperbolae, fitted by nonlinear regression analysis. (Note that values of r refer to frequencies of delivery of positive reinforcement; punishment frequency has not been subtracted; note also the different ordinate scales used for the four subjects.)

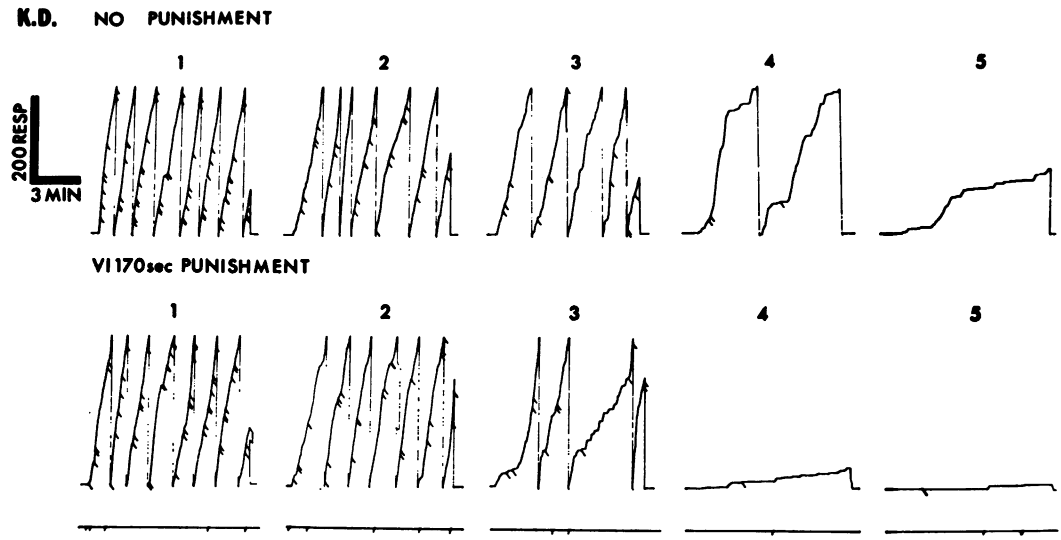

Fig. 2. Sample cumulative records obtained from one subject showing the final session without punishment and the final session with punishment. Diagonal deflections on cumulative traces indicate reinforcements; deflections on fixed traces indicate punishments. Numbers above the records indicate the five variable-interval schedules: 1, VI 8-sec; 2, VI 17-sec; 3, VI 51-sec; 4, VI 171-sec; 5, VI 720-sec. (The schedules were presented in quasirandom sequence, see Method, but have been rearranged in the figure so that performance in the absence and presence of punishment may be compared.) Note the progressively decreasing response rates with lower reinforcement frequencies, and the greater suppressant effect of the punishment schedule on performance under low reinforcement frequencies.

sponse rate (K_H). The estimated values of the constants are shown in Table 1. The index of determination (p^2) was calculated for the curve obtained from each subject (p^2 expresses the proportion of the variance of the y-values which can be accounted for in terms of x, in a curvilinear function [Lewis, 1960; see also Bradshaw *et al.*, 1976, 1977]). The values of p^2 were 0.920 (CW), 0.962 (JC), 0.887 (BH), and 0.991 (KD).

Performance in the Presence of VI Punishment

Figure 1 (open circles) also shows, for each subject, the mean response rates (R ± s.e.m.) recorded under each schedule during the last three "Bad Days" (with VI 170-sec punishment) plotted against reinforcement frequency (r). (A sample cumulative record obtained from one subject, KD, is shown in Figure 2.) Rectangular hyperbolae were fitted to the data by the method of Wilkinson (1961). The estimated values of the constants (R_{max}' and K_H') are shown in Table 1. The values of p^2 were 0.900 (CW), 0.966 (JC), 0.942 (HB), and 0.994 (KD).

There was a marked suppression in all four subjects of responding in the presence of punishment under lower frequencies of reinforcement, whereas there was much less discrepancy

Table 1

Estimated values of the constants (±s.e.est.), obtained by nonlinear regression analysis from plots of response rate *versus* delivered reinforcement frequency (see Figure 1).

	No Punishment		*VI 170-sec Punishment*	
Subject	R_{max} (*resp/min*)	K_H (*reinf/hr*)	R_{max}' (*resp/min*)	K_H' (*reinf/hr*)
CW	299.8 (±5.3)	1.4 (±0.3)	288.3 (±17.8)	7.8 (±2.8)**
JC	81.6 (±5.1)	14.2 (±4.5)	86.0 (±9.2)	48.6 (±20.0)*
HB	86.9 (±3.0)	2.7 (±0.7)	94.9 (±9.7)	24.9 (±11.1)*
KD	294.8 (±15.6)	67.7 (±12.1)	368.3 (±43.8)	219.6 (±6.1)**

Significance of change in the values of the constants (normal t-distribution): *$p < 0.05$; **$p < 0.02$.

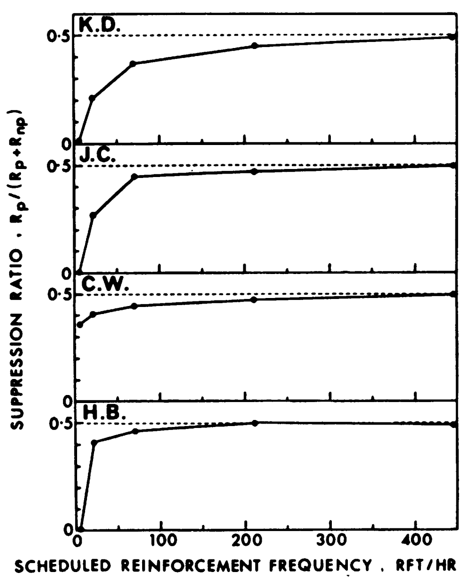

Fig. 3. Relationship between degree of response suppression in the presence of punishment (VI 170-sec punishment) and frequency of positive reinforcement. *Ordinates:* suppression ratio (response rate in the presence of punishment, R_p, as a fraction of the sums of the response rates in the absence and in the presence of punishment, $R_p + R_{np}$). A ratio of 0.5 indicates no suppression; a ratio of 0 indicates complete suppression. *Abscissae:* reinforcement frequencies specified by the five variable-interval schedules of positive reinforcement. In all four subjects, the punishment schedule produced a more profound suppression under low reinforcement frequencies than under high reinforcement frequencies.

between punished and unpunished performance in the high-density VI schedules (Figure 3). This was reflected in statistically significant increases in the estimated values of K_H, with no significant changes in the values of R_{max}, in the presence of punishment (Table 1). (Note that in the case of KD, there was a considerable increase in the value of R_{max} in the presence of punishment; however, this increase did not achieve statistical significance: $p > 0.1$). The estimated values of K_H were increased by factors of 5.6 (CW), 3.4 (JC), 9.2 (HB), and 3.2 (KD).

Delivered versus *Scheduled Reinforcement Frequency*

In the absence of punishment, the delivered reinforcement frequency was between 5% and 15% lower than the scheduled reinforcement frequency. Similar discrepancies occurred in the presence of punishment, except in the case of JC's and HB's performance under Schedule 5 (VI 720-sec). Under this schedule, these subjects responded at rates of less than 0.5 responses per minute, and each received only one reinforcement during the last three "Bad Days". Thus, the discrepancy between scheduled and delivered reinforcement frequencies was greater than 50% in these cases.

DISCUSSION

The results obtained in the absence of punishment confirm our previous reports (Bradshaw *et al.*, 1976, 1977) that Herrnstein's equation is applicable to human behavior under VI schedules of reinforcement.

Several writers have emphasized the role of the instructions in controlling schedule performance by human subjects (Baron, Kaufman, and Stauber, 1969; Baum, 1975; Kaufman, Baron, and Kopp, 1966; Matthews, Shimoff, Catania, and Sagvolden, 1977). Matthews *et al.* (1977) suggested that instructions may be critical in determining whether human performance is comparable to animal performance under many schedules. In the present experiments, the subjects were instructed how to operate the manipulandum, but were not informed about the various schedule dependencies. It is of interest that the conformity of the subjects' response rates to the hyperbolic function is consistent with observations made on pigeons (Catania and Reynolds, 1968; Herrnstein, 1970) and on rats (Bradshaw, 1977).

In agreement with Bradshaw *et al.* (1977) and Weiner (1962), the present results show that punishment, in the form of response cost, can suppress the responding of human subjects under VI schedules of reinforcement. However, there are marked differences between the pattern of response suppression seen in the present experiments, using a VI punishment schedule, and the pattern observed in our previous study, in which a VR punishment schedule was employed. In our earlier experiment, the suppression of response rates was reflected both in a reduction in the value of R_{max} and an increase in the value of K_H. In the present experiment, however, an increase in the value of K_H was found, with no significant change in the value of R_{max}. Although direct quantitative comparison of the results of the two studies is not feasible, since the punishment densities were not equal, it is apparent that the patterns of response suppression produced by the two types of punishment schedule are *qualitatively* different. While the role of punishment density in producing this qualitative difference cannot be excluded without further parametric study, this difference between the results of the two experiments may reflect the different punishment schedules employed in the two studies, since the apparatus, schedules of reinforcement, and instruction given to the subjects were identical in the two cases. Our findings are consistent with the suggestion of Azrin and Holz (1966) that the suppressive effects of punishment on operant behavior depend in part on the type of punishment schedule used. According to the present scheme for classifying variables that suppress the rates of responding in VI schedules, punishment delivered on a VI schedule resulted in an increase in K_H (category ii), whereas punishment delivered on a VR schedule increased K_H and reduced R_{max} (category iii).

Our finding that punishment delivered under a VI schedule has a more profound suppressant effect on responding maintained by low reinforcement frequencies, than on responding maintained by high reinforcement frequencies, is consistent with data from animal experiments employing food reinforcement and electric shock as the punishing stimulus. Church and Raymond (1967), using rats, found that electric shock delivered under a VI schedule reduced response rates more than when the food reinforcement schedule was VI 2-min than when it was VI 0.2-min. Similarly, de Villiers (1976), using a two-key concurrent procedure with pigeons, observed that shock delivered under a VI schedule produced greater suppression of key pecking maintained by VI 3-min than of pecking maintained by VI 1-min food reinforcement. In contrast, when electric shock follows every response, the per cent response suppression is independent of the frequency of reinforcement (Holz, 1968).

REFERENCES

Azrin, N. H. and Holz, W. C. Punishment. In W. K. Honig (Ed), *Operant behavior, areas of research and application*. New York: Appleton-Century Crofts, 1966. Pp. 380-447.

Baron, A., Kaufman, A., and Stauber, K. A. Effects of instructions and reinforcement on human operant behavior maintained by fixed-interval reinforcement. *Journal of the Experimental Analysis of Behavior,* 1969, **12,** 701-712.

Baum, W. M. Time allocation in human vigilance. *Journal of the Experimental Analysis of Behavior,* 1975, **23,** 45-53.

Bradshaw, C. M. Suppression of response rates in variable-interval schedules by a concurrent schedule of reinforcement. *British Journal of Psychology,* 1977, **68,** 473-480.

Bradshaw, C. M., Szabadi, E., and Bevan, P. Behavior of humans in variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1976, **26,** 135-141.

Bradshaw, C. M., Szabadi, E., and Bevan, P. Effect of punishment on human variable-interval performance. *Journal of the Experimental Analysis of Behavior,* 1977, **27,** 275-279.

Catania, A. C. and Reynolds, G. S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 327-383.

Church, R. M. and Raymond, G. A. Influence of the schedule of positive reinforcement on punished behavior. *Journal of Comparative and Physiological Psychology,* 1967, **63,** 329-332.

de Villiers, P. Choice in concurrent schedules and a quantitative formulation of the law of effect. In W. K. Honig and J. E. R. Staddon (Eds), *Handbook of operant behavior*. Englewood Cliffs: Prentice-Hall, 1976. Pp. 233-287.

Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior,* 1970, **13,** 243-266.

Herrnstein, R. J. Formal properties of the matching law. *Journal of the Experimental Analysis of Behavior,* 1974, **21,** 159-164.

Holz, W. C. Punishment and rate of positive reinforcement. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 285-292.

Kaufman, A., Baron, A., and Kopp, R. E. Some effects of instructions on human operant behavior. *Psychonomic Monograph Supplements,* 1966, **1,** 243-250.

Lewis, D. *Quantitative methods of psychology*. New York: McGraw-Hill, 1960.

Matthews, B. A., Shimoff, E., Catania, A. C., and Sagvolden, T. Uninstructed human responding: sensitivity to ratio and interval contingencies. *Journal of the Experimental Analysis of Behavior,* 1977, **27,** 453-467.

Weiner, H. Some effects of response cost upon human operant behavior. *Journal of the Experimental Analysis of Behavior,* 1962, **5,** 201-208.

Wilkinson, G. N. Statistical estimations in enzyme kinetics. *Biochemical Journal,* 1961, **80,** 324-332.

Received 5 August 1977.
(Final acceptance 7 September 1977.)